An Innovative Pile Guide Wall for the Emden Sea-Lock

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1. Emden seaport, an Introduction.

The Port of Emden is situated in the North-Sea on the western border of the German Bight in the Ems-River estuary. The access to Emden port is possible for vessels up to 80.000 dwt via the Emden fairway. Using the tidal situation in the estuary, drafts up to 10.7 m (35 ft) can be accommodated at high tide. The outer harbour is under the influence of the tidal range. To arrive at the inner port it is necessary to lock in the small „Lock Nesserland" which is 110 years old", or in the so called „Great Sea-lock" built in the early 20th century.

The port of Emden is known world-wide as the distribution hub for cars manufactured by the German Volkswagen Company. In the year 2000, the annual port turnover will reach 1 million cars. Other goods handled in the port of Emden are containers (100.000 TEU), forest products (1 million tons) and liquefied marble (1 million tons).

2. Renovation of the Great Emden-Sea-Lock

The bottleneck to the inner port of Emden is the Great Emden-Sea-Lock. This sea-lock, now nearly 100 years old, was renovated between 1993 and 1997. The most important works were to built new roller gates and machinery on the inner and outer lock heads, with new tracks installed on the bottom. The masonry of the lock-chamber was renewed. The budget for renovation was 48,5 million DM, which was approximately $35 million at that time.

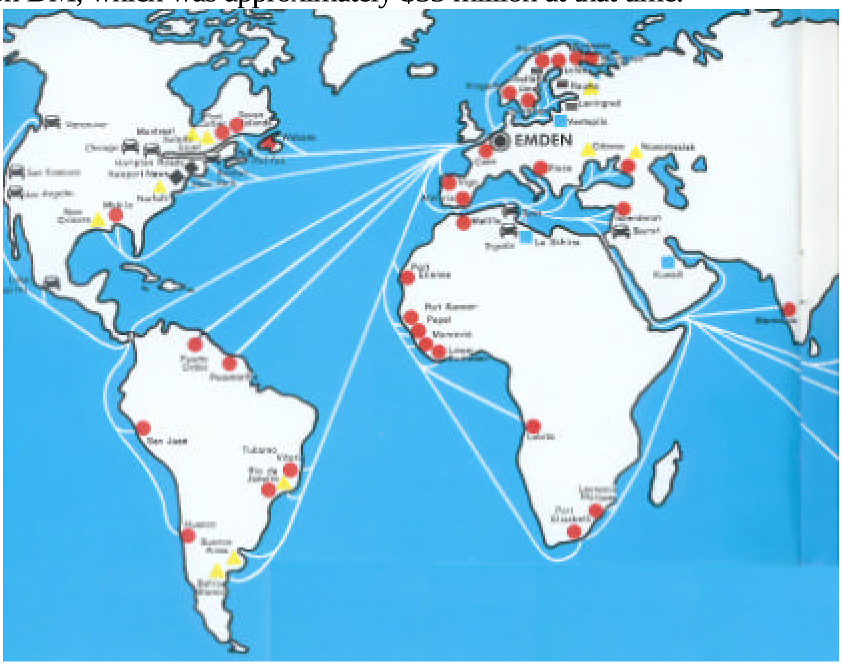

Fig.1: Port of Emden in the world

A very important part of the renovation and improvement of the sea-lock was the new guidance system in the outer advance port. Very often in the past, impacts occurred between vessels and the masonry or the gate in the outer lock head. Before the vessels impacted the lock-head, they pushed against one of the dolphins, which were positioned before the lock. The location of the dolphins and the system were not optimized. The German consultant engineering firm CES (Consulting Engineers Salzgitter) was asked to analyze the fender-system and to recommend a better guidance-system for big vessels approaching the sea-lock.

3. The access to the „Great Emden Sea-lock“

3.1 Former situation

The Emden Sea-lock has a length of 260 m (853 ft), a width of 40 m (131 ft) and a depth of 11.76 m (42 ft) at high tide (9.82 m to Chart Datum). It was built in the years 1907 to 1913.The sea-lock is the connection between the outer and the inner ports of Emden. The dimensions allow the normal access of vessels to 255 m (836 ft) length and 35,5 m (116 ft) width. Panamax vessels need the assistance of 4 tug boats.

To facilitate access to the lock chamber in the advance port, three guidance dolphins on port side and four dolphins on starboard side had been installed. The lock-head corners are protected with rolling fender-wheels. However, there were many collisions between the vessels and the dolphins, outer lock gate and outer lock-head. When damage occurred, the sea-lock normally had to be closed for a day to change the lock gates or to repair the damage on the lock-heads, concrete and masonry. It became evident that the guidance system needed to be improved to ensure that vessels were able to dock in the lock chamber without any impacts and damages to the ship or the lock side.

3.2 Analyzing several accidental excessive impacts in the lock advance port

CES conducted a study of 12 reports of accidents that had happened between 1974 and 1993. The lengths of the vessels in the study were more than 200 m (656 ft) long with width of more than 32 m (105 ft). Normally, the vessels belonged to the Panamax-class of bulk carrier. A common observation was that a collision the lock-head often occurred after contact with one of the port side dolphins.

Fig.2: Emden Sea-Lock (former Situation)

The four main problems identified in the study were:

- The access port of the lock is very short for Panamax vessels.
- The main wind direction is from west to southwest, and the wind force works very unfavourable to vessels maneuvring.
- The tidal current in the Ems River is very strong where the vessels leave the Emden fairway to enter the access port.
- Due to an asymmetrical access port, the current is not equal on both sides of the vessel.

It was recommended to change the axis of the port side guidance line and open it for 5°. It was also determined that 3 dolphins were not enough, and that it would be better to lengthen the dolphin line to 120 m (394 ft) by adding 3 more dolphin points (6 total). To optimize the dolphins, it was decided to employ a fender system that utilizes floating fenders that rotate around elastic mono-pipe pile.

3.3 Layout criterion for the new guidance system

Together with the harbour-master and the pilots, the Emden port planning division adapted the CES recommendation and planned the final system under the following criteria [1]:

- The guidance system must be implemented in a step-by-step process. This means that as a first step, the port side dolphin system must be modified.
- The alignment of the dolphin axis should be 3° open to the lock axis. This exists on starboard side, but should be also implemented on port side. The dolphin axis should be the same as the dredging axis to the access port.
- Vessels must be able to stop and to berth on the dolphin line. The next maneuvre should bring the vessel safety into the lock chamber.
- The entrance width of the sea-lock must be more than 38,70 m (127 ft). An impact of vessels leaving the lock towards the sea is not allowed.
- The new guidance system must be able to have an energy absorption capacity of more than 1.200 kN-m (885 ft-kips) with an impact force of 1.600 kN (359 kips).
- The friction between ships skin and fender surface is to be minimized.

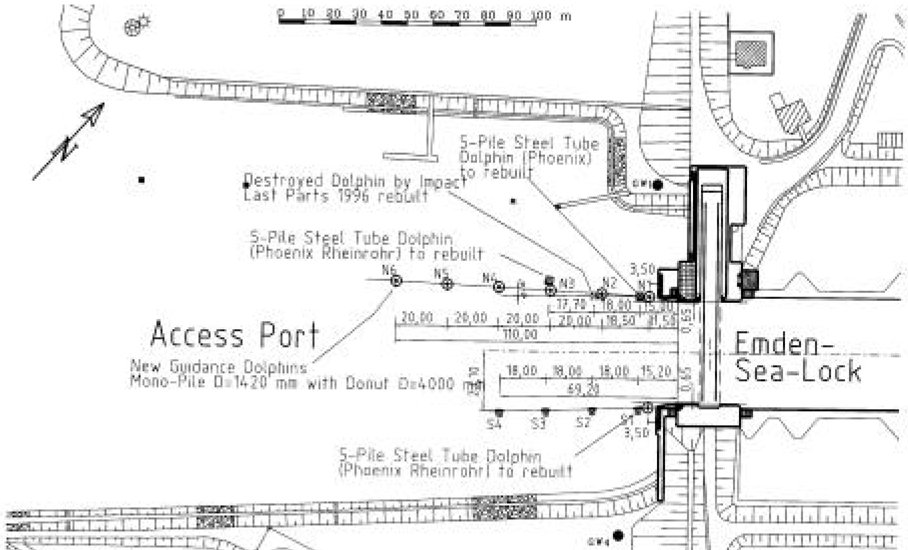

Fig. 3: General Layout of Emden Sea-lock access port with new fender-line

The port-side guidance should be made out of six single dolphins in a line of 120 m (394 ft) long. The distance between the dolphins should be 20 m (65.6 ft) to guarantee that the vessels cannot leave the maneuvre lane. On the starboard-side, there should be another dolphin situated near the lock-head corner to guide the vessels safety into the lock chamber.

4. Interactive system fendering-element/dolphin

Only a combined system made of a dolphin and a rubber or foam fender is able to absorb the ships impact energy without danger to the vessel or the dolphin, and also help guide the vessel safety back into the maneuvring line. The effect of this interactive system must be investigated for several cases. There is a continuous change in energy input into the fender and into the dolphin. The vessel size and velocity determine which element is active at one time. It must be also determined if only a mono-pile is best or if a pile group is necessary to achieve the optimal efficiency.

In the past, mono-piles and pile groups normally were equipped with rubber fender elements and big wooden panels in a steel frame. Because of vessels impacts, it was well known that damages and the costs for repair can be very high. Also, the maintenance group needs a long time to make repairs, and the lock-head is without protection during this time period. If a mono-pile and floating fender-ring (a so called Donut fender) system is utilized, it must minimize all problems if the Donut will be required to absorb more than a quarter of the total energy absorption capacity.

An advantage of this system is that, especially for smaller vessels, the total height of the floating Donut can be contacted by the ship. The Donut can rotate around the pile and therefore eliminate sliding friction between the vessels hull and the Donut.

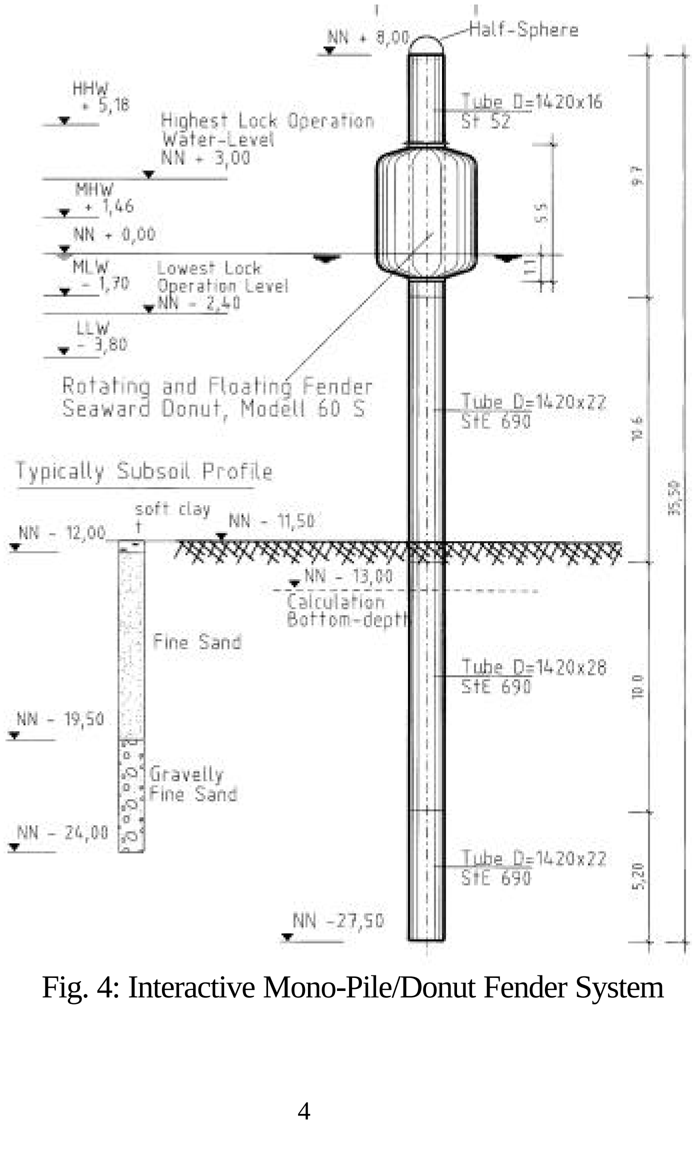

Fig. 4: Interactive Mono-Pile/Donut Fender System

A cost-benefit analysis shows that normally higher costs for a Donut system will be equalized by lower costs for future maintenance and repair costs for the vessel and the lock head. Also, the insurance costs for ships is lower if they dock in a safe port rather than in a dangerous port with many navigation problems.

The theoretical decision to utilize a mono-pile-Donut system needed to be verified in discussions with a Donut manufacturer. Is it possible to manufacture a Donut in the calculated dimensions with the correct energy input?

The first calculation indicated that a mono-pile diameter ~1,40 m (4.60 ft) would be required. To achieve an energy input to the pile of 900 kN-m (664 ft-kips) the Donut needs to absorb 300 kN-m (221 ft-kips).

However, the correct dimensioning of the Donut brought some difficulties. The maximum Donut diameter ever was made was 4.20 m (13.78 ft). Therefore, it was decided to manufacture the Donut with an outer diameter of 4,00 m (13.12 ft) and an inner diameter of nearly 1,40 m (4.6 ft), with a clearance of two cm (0.8 inch) between the Donut and the mono-pile. Looking at existing Donuts with a diameter of approximately 4,00 m (13.1 ft) shows that an energy absorption capacity of 350 kN-m (258 ft-kips) should be possible. Using the German BLUM method for geotechnical dolphin calculations, it was determined that a mono-pile with a diameter of 1.420 mm (4.66 ft) would actually be required. The mono-pile should be designed in 5 sections with different steel plate thickness and different high-strength steel qualities.

4.1 Donut Floating Fender

The German recommendations of the committee for waterfront structures (EAU) give some very good instructions for composite mono-pile design in publication R 112 [2]. Donuts of such large diameters are not in the normal manufacturing range of the manufacturers. Therefore, the Port of Emden Authority asked in the tendering documents for a model-test to demonstrate that the needed energy absorption capacity would be reached in the full scale Donut. To get this energy, the inside foam quality is very important.

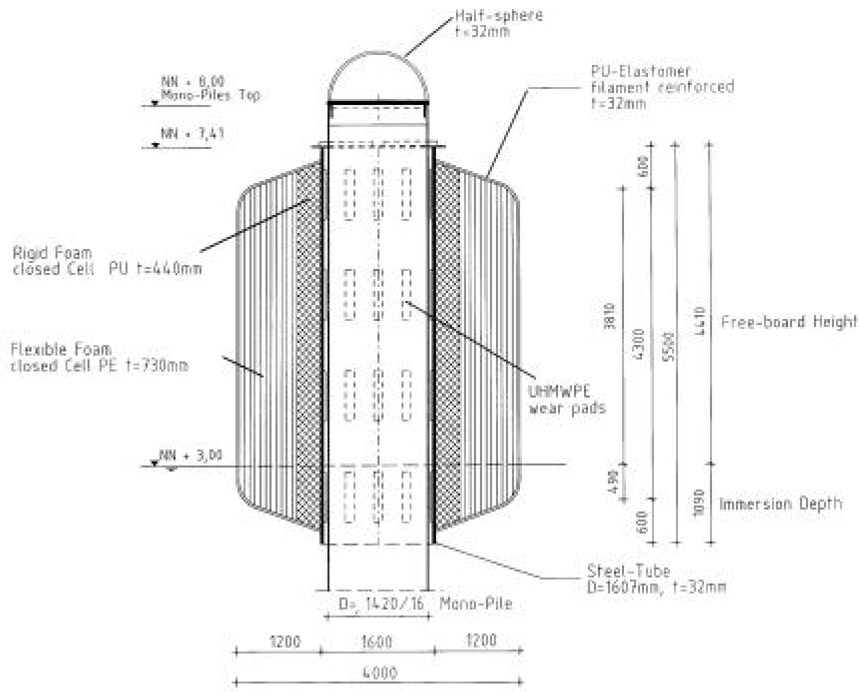

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Fig. 5: Section of the Donut

In addition to the energy absorption capacity is the requirement of some ships owners to guarantee a maximum of hull pressure not to exceed 200 kN/m² (44.9 kips/m²). Therefore, the Donut height was to be 5,50 m (18.04 ft).

With a Donut model (scale 1:5) the tests were made at Seaward International, Inc. (because Seaward was the winner in an international competition). The results were fully satisfied.

4.2 Mono-Pile Dolphin

The final dolphin calculation gave a mono-pile diameter 1,420 mm (4.66 ft), steel-plate thickness between 16 mm and 28 mm (0.63 to 1.1 inch), steel quality ST-E 690 from the location of the highest bending moment down into the subsoil and steel quality S 355 GP in the section above the bottom. The top of the pile is at CD +10.00 m (32.8 ft.) and is therefore 6 m (19.7 ft.) higher than normal high water (CD = chart datum). The pile is driven down into the bottom to CD –25,50 m (-83.7 ft.). The overall pile length is 35.50 m (116.5 ft.) and the weight is 9.25 tons. The deflection due to a vessels impact at the top of the pile had to be less than 1.50 m (4.31 ft.), otherwise an incoming vessel with a portside list could be able to touch it. The pile-head was made out of a half-sphere.

In Germany a static calculation is needed to show that there no swelling in tubes used to take off bending moments. This calculation was satisfactory, as was the calculation to show that the continuous impact due to wave forces was acceptable.

5. Execution works

5.1 Tendering and award

The tender documents and the general layout of the fender system were given by the Emden port authority. The scope of the works was to manufacture mono-piles and Donut fenders, vibrate the piles into the bottom and equip the piles with the Donuts. For manufacturing the Donuts, only companies were considered that could show that they have made Donuts with the required dimensions. It was also permissible to offer an alternative fender system if the company could prove that the alternative system was more economical than the Donut system, especially with regard to the maintenance. No alternative offers were submitted, so it was concluded that there was no better solution on the market than the Donut/mono-pile design.

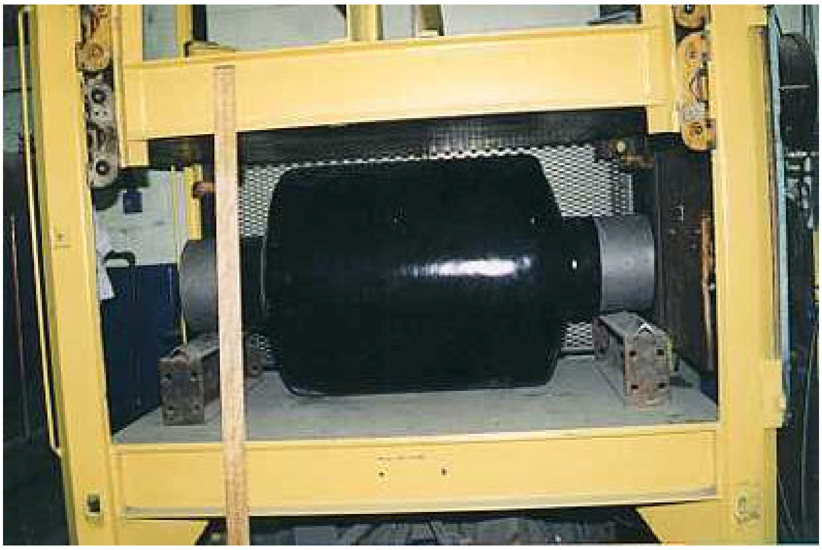

Fig. 6: Donut model testing; Scale 1:5

5.2 Design and manufacturing of the Donuts

The Seaward International, Inc. Model 60-S Donut fender was constructed with an outside diameter of 4.00 m, a flat side height of 4.30 m, and an overall height of 5.50 m. Freeboard was 4.41 m and draft was 1.09 m. The energy absorption capacity was 320 kN-m at a reaction force of 1,600 kN. Deflection of the Donut at this condition was 0.43 m.

The Donut was equipped with ultra-high molecular weight polyethylene (UHMWPE) wear pads on the inside surface of the steel core to bear against the mono-pile and minimize frictional resistance while rotating under load. In addition, the top edge of the fender was equipped with additional wear pads in case of the vertical rise of the fender during extreme high water conditions caused the Donut to contact a flange bolted to the pile.

However, it was decided later not to install a flange on the pile. The 32-mm thick Donut skin was made from filament reinforced polyurethane elastomer.

Installation of the Donut was simple. Using a sling attached to lifting eyes built into the top edge of the Donut, a crane lifted the Donut over the pile and then lowered it into the floating position. Upon removal of the lifting slings, the Donut was immediately operational.

5.3 Mono-Pile Dolphins

The mono-piles were manufactured in East-Germany by the "Röhren- und Behälterbau – Aschersleben". The 35.50 m long and 29.7 tons piles were driven into the bottom by using a very strong vibrator. The subsoil conditions had been investigated before and the sand was found to be easy to penetrate.

Only the rebuilding of the old dolphins presented some difficulties, because thick layers of silt had to be removed to burn the piles off at a deep level. The total work-time on-site was only seven days and was completed in September 1999. At this time maneuvring of vessels began to proceed very smoothly.

6. Permanent documentation of vessels impact against the dolphins

Before the new system was installed, one of the existing dolphins had been equipped in the past with a very simple system of deflection measurement. As a result, the harbor-master was able to say if there was an impact or not. But due to the very complex fender system created with the existing 5-pile dolphin, it was not possible to back-calculate the ship velocity or the height of the impact.

Fig.7: Transport of the finished Donut to Baltimore for shipping to Emden

Fig.8: New Donut guidance system in the Sea-Lock access port

Today we have very sophisticated electronic systems, so it was decided to equip the mono-pile dolphin with a “black box” on the top to measure piles motion. Measurements included acceleration due to the impact, and deflections on the top of the pile, both before and after the impact.

A radar sensor also records the vessels velocity in the last seconds before it contacts the Donut. All measurements are permanently stored in a computer installed in the lock operation centre.

Because there are movements of the dolphin due to waves or wind, special analysis software determines if the event is significant. The radar sensor starts to measure if the ship is less than 20 m away from it.

Unfortunately, it is not yet possible to economically measure the forces and the deflection of the Donut itself. Many sensors integrated in the Donuts skin would be necessary to provide information about the impact. One method has been considered is to photographically record the deformation of the skin. Together with the other measurements, and the data provided by the ships owner, it may be possible to determine the complex interactions between the Donut and the monopile.

Presently, the recorded data include:

- Berthing velocity of the vessels by calculation,
- Acceleration of the pile after absorption of the first impact by the Donut,
- Deflection of pile head,
- Permanent deformation of the pile,
- Vessel velocity by radar sensor,
- Data from the vessel and the displacement calculation.

Another future step is recording the course of the vessel, so that it will be possible to compare the actual turning angle α with the calculated angle.

The data so far has shown that the motion characteristics of the pile when impacted with a small vessel with high berthing velocity are completely different than the impact or a large vessel with a low berthing velocity. The angle vs. time diagrams gives a good information here. Normally, the impact of the small fast ship deflects the pile first and than the Donut, but the large slow ship deflects the Donut first and than the pile. However, the overall deflection is the same in both cases. Only if the impact to the dolphin is higher than the calculated limit does permanent deformation occur. Once more information is known about the boundary conditions, it will be possible to determine what really happens during an impact.

7. First experience

The "black box" installed on dolphin no. 4 has been in operation since February 2000. Several impacts have been registered [3]. The first impacts were performed by one of the port tugboats to get measurements to calibrate the system. It was a surprise to find out that the acceleration of the pile in the moment of the impact is nearly 10 g.

In addition to the damage protection, the new system is able to provide the following operational benefits:

- It gives the pilots a visual reference to the correct approach to the lock.
  After an impact with the dolphins, the rotating Donuts guide the vessel smoothly in the proper direction.
- The pilots can use the new fender line like a berth. First they stop the vessel and then they let the wind and current push the vessel to the Donuts. From there, they maneuver the ship under low power into the lock chamber.

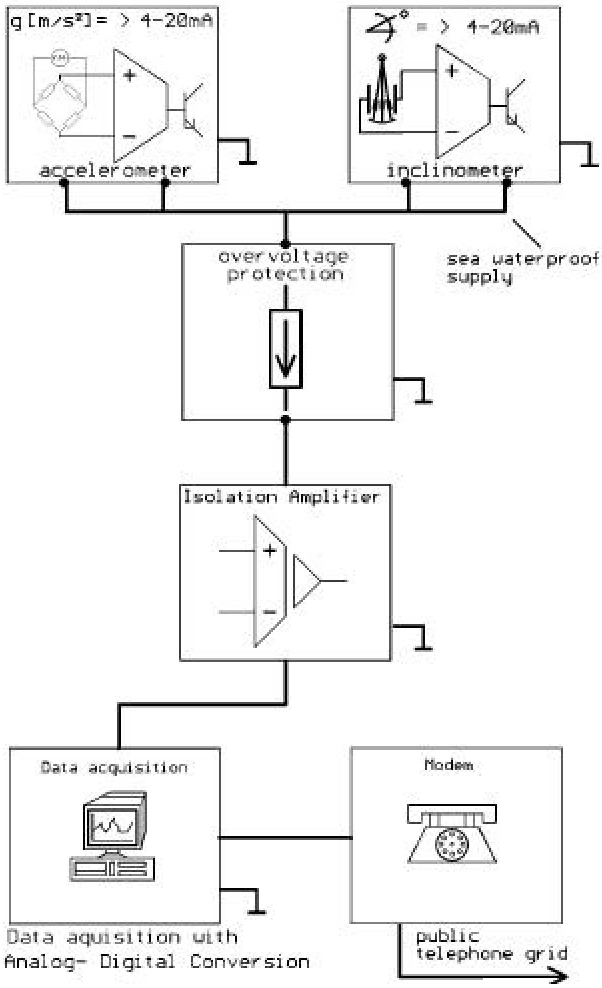

Fig.9: Block Diagram of Deformation Measurement (System ARGUS)

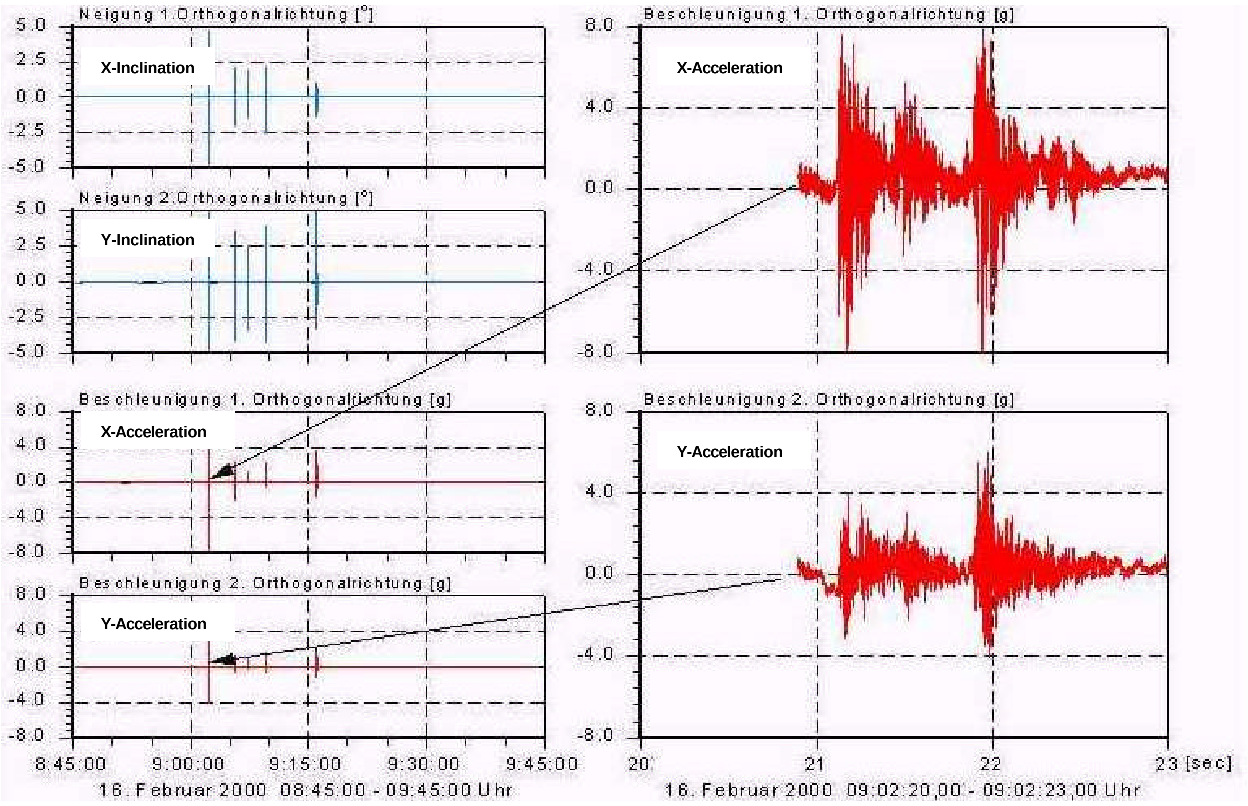

Fig. 10. Measurement of acceleration due to an impact against the Donut

8. Summary

In 1999 at the Port of Emden (Germany), the first dolphins with floating fender-rings called “Donuts” were installed to ensure safe access into the Emden Sea-Lock. It was shown that the system was very quick to build and to activate. In only seven days, 7 mono-pile dolphins were driven, equipped with the Donut fenders, and turned over for the use by the vessels entering the lock.

The installed costs of this seven-dolphin system were $175.000 per dolphin.

References:

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2: EAU 1996; Recommendations of the Committee for Waterfront Structures, Harbours and Waterways; Ernst&Sohn, Berlin 1996

3: Clasmeier, H.D.; Manzenrieder, H.; Gutkuhn, J. Überwachung von lastbedingten Dalbenverformungen im Tidegebiet; Symposium Messen in der Geotechnik 2000, Techn. Universität Braunschweig 2000